

(NASA-CR-142194) COLLECTION AND
CONCENTRATION OF SOLAR ENERGY USING FRESNEL
TYPE LENSES Final Summary Report (Texas
Southern Univ.)

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A FINAL REPORT AND SUMMARY ON RESEARCH PROPOSAL OF APPLIED
SOLAR RESEARCH

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TITLE OF RESEARCH PROPOSAL "Collection and Concentration of Solar Energy Using
Fresnel Type Lenses"

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"COLLECTION AND CONCENTRATION OF SOLAR ENERGY USING FRESNEL TYPE LENSES"

In this study, the efficiency of collecting solar energy using a Fresnel type lens was measured employing two different collectors. The two collectors, one a flow collector and the other a static collector, are described in the following pages.

I. A Dynamic or Flow Heat Collector

Description of Apparatus:

A picture of the flow collector is shown below in figure 1. The collector's wall, walls top and bottom were constructed using acrylic plexiglass plates and tubing, obtained from Cadillac Plastics, Houston, Texas. The various component parts of the collector after being machined for proper fit were glued together using Day-bound cement. The inner compartment of the collector contained a circular copper metal plate, coated with black velvet paint #101-C10 obtained from Curtin Chemical, Houston, Texas, which was attached to the bottom of this compartment by three insulation bakelite supports. The second or middle compartment was filled with insulating material, Florco-X-All Purpose Absorbent, obtained from the Floridin Company, Pittsburg, Pennsylvania. The third or outer compartment was fitted with an outlet tube for evacuating the outer chambers using a vacuum pump. The collector's water inlet and outlet tubes were constructed with sealed thermometers for measuring the temperature of the incoming and outgoing water. From the temperature difference and the heat capacity of water, the amount of energy absorbed and retained from the sun rays passing through the Fresnel lens was calculated. Meanwhile, the total amount of energy incident upon a unit area of the lens was measured using a IL500 Research Radiometer obtained from International Light Company, Newburyport, Massachusetts. From these data the percentage efficiency of the collector was calculated.

Figure 1



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COLORED ILLUSTRATIONS

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Figure 2 below gives a brief schematic and operational description of the constant flow collector that was designed, constructed, and used throughout this investigation. Detailed specifications of this apparatus are given in Appendix 1.

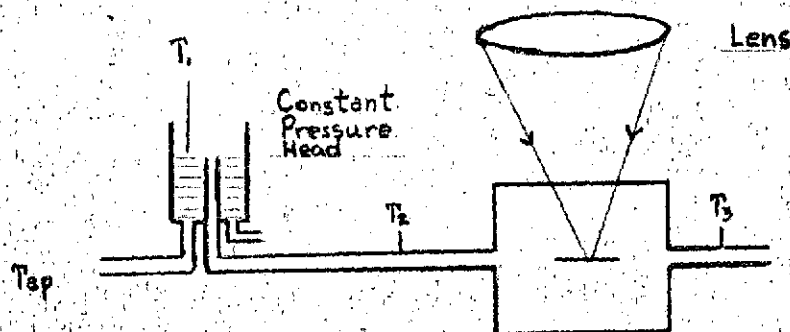


Figure 2, Flow Collector

Measurements using the flow collector were carried out by maintaining a constant flow of water over the collector as indicated in the arrangement shown in Figure 2, and the focusing of the radiations passing through the Fresnel lens was continuously adjusted using an electrically driven equatorial mount, Model No. 85112, obtained from Edmund Scientific Company, Barrington, New Jersey. After the thermometers T_1 and T_3 attained steady temperatures, the rate of the flow of water was measured. A radiometer (International Light Company, Model IL500) was used to measure the radiation flux incident on the lens.

A typical observation:

$$T_1 = T_2 = 28.5^{\circ}\text{C}, T_3 = 38.0^{\circ}\text{C}$$

$$\text{Rate of flow} = 152 \text{ ml/2 min. or } 1.27 \text{ ml/sec}$$

$$\text{Radiation flux incident on the lens} = 560 \text{ watt/m}^2$$

$$\text{Area of cross-section of the lens} = 0.118 \text{ m}^2$$

$$\begin{aligned} \text{Power of incident on the lens} &= 560 \times 0.118 \text{ m}^2 \\ &= 66 \text{ watts} = 15.8 \text{ cal/sec} \end{aligned}$$

$$\begin{aligned} \text{Power carried by the water} &= \text{rate of flow of water} \times \text{specific heat of water} \times \text{temperature change} \\ &= 1.27 \times 1 \times (38.0 - 28.5) \text{ cal/sec} \\ &= 12.1 \text{ cal/sec} \end{aligned}$$

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$$\% \text{ Efficiency} = \frac{12.1}{15.8} \times 100 = 77$$

See Appendix, Table 1, for additional data.

However efficiencies varying from 65% to nearly 80% were obtained under different conditions of temperature, variation in the constant flow rate, etc., using the constant flow apparatus. As there is a large volume of water (1530 ml) surrounding the absorber plate, heat exchange between the flowing water and the rest of the water surrounding the plate could be partially responsible for these varying results. In order to eliminate this possible effect, the design of the equipment may have to be changed.

II. A Static Collector:

The heat collector (see Appendix) is a hollow copper box made of copper with exterior dimensions of 7.0 cm x 7.0 cm x 1.6 cm. The top of the box contained a small opening for adding and removing liquids. All surfaces of the static collector including its two support arms, except the front surface were covered with asbestos wrappings. The front surface of the collector was coated with black velvet paint (previously described) and fitted with a glass plate separated from the surface by a small air space of several millimeters. The copper box was filled with vegetable cooking oil (Crisco) used as a heating fluid and the solar radiation was focused from the Fresnel lens through the glass plate upon the black coated surface.

The Fresnel lens was mounted on an electrically driven equatorial mount (Edmund Scientific Company, Model No. 85112) and the collector was mounted at the focus of the lens. Continuous automatic focussing was achieved through this arrangement. The temperature of the collector was measured with a mercury thermometer. Maximum equilibrium temperatures of approximately 185°C were easily obtained using this arrangement, although there was an appreciable loss of heat due to conduction, convection and radiation. It may be observed that the maximum temperature of the fluid and the collector depends upon the physical dimensions and the surface conditions of the collector. When a soft-glass plate was attached to the front surface of the collector, maximum temperatures in the range of 185°C were obtained, but the glass plate generally cracked after a few hours of exposure. These results suggest that more suitable glass such as vycor or pyrex should be properly separated and cemented to the front face of the static collector in order to take full advantage of the greenhouse effect. Also proper methods of cementing the glass plate should be investigated further.

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First, the temperature of the oil and the can as a function of time, was measured with the radiation incident on the face of the collector. Second, the lens was covered and the temperature decrease due to conduction, radiation, etc., as a function of time was measured. From these measurements it is apparent that

$$P \text{ (Power received by the collector)} = P_A + P_r,$$

where P_A is the power retained by the collector, resulting in temperature increase, and P_r is the power lost by the collector due to conduction, radiation, etc.

$$P_A = C \text{ (Thermal capacity of the collector)} \times \frac{dT}{dt}$$

where $\frac{dT}{dt}$ is the rate at which temperature would change with time when solar radiation is incident on the face of the collector. Similarly,

$$P_r = C \times \left| \frac{dT_r}{dt} \right|$$

where $\frac{dT_r}{dt}$ is the rate of change of temperature with time due to conduction, radiation, etc. Thus

$$P \text{ (Power received by the collector)} = C \times \frac{dT}{dt} + \left| \frac{dT_r}{dt} \right|$$

Observations:

See Table II for the temperature versus time data for the heating and cooling of the Static heat collector. Graphical presentation of the data is shown in fig. 3. Slopes of the curves, representing the rates of change of temperature are read at $T = 100^\circ\text{C}$ and $T = 50^\circ\text{C}$.

$$\text{At } T = 100^\circ\text{C}, \quad \frac{dT}{dt} = 5.3^\circ/\text{min}$$

$$\text{and } \left| \frac{dT_r}{dt} \right| = 13.2^\circ/\text{min}$$

$$\frac{dT}{dt} + \left| \frac{dT_r}{dt} \right| = 18.5^\circ/\text{min}$$

$$\text{At } T = 50^\circ\text{C}, \quad \frac{dT}{dt} = 15^\circ/\text{min}$$

$$\text{and } \left| \frac{dT_r}{dt} \right| = 5.5^\circ/\text{min}$$

$$\frac{dT}{dt} + \left| \frac{dT_r}{dt} \right| = 20.5^\circ/\text{min}$$

$$\text{On the average } \frac{dT}{dt} + \left| \frac{dT_r}{dt} \right| = 19.5^\circ/\text{min.}$$

Thermal capacity of the collector (oil + box) = 28.4 cal/degree

$$P = \text{Power received by the collector} = 28.4 \times 19.5 \text{ cal/min} \\ = 9.2 \text{ cal/sec}$$

$$\text{Radiation flux incident on the lens} = 560 \text{ watts/m}^2$$

$$\text{Area of the lens} = 0.118 \text{ m}^2$$

$$\text{Power incident of the lens} = 560 \times 0.118 \text{ watts}$$

$$= 66 \text{ watts}$$

$$= 15.8 \text{ cal/sec}$$

$$\% \text{ Efficiency} = \frac{9.2}{15.8} \times 100 = 58$$

The design of the collector should be improved so that losses are minimized. It should be possible to construct collectors which reach equilibrium at 300°C or above. Maintaining such a collector well below the equilibrium temperature, for example, 200°C, heat can be extracted by a flowing liquid.

The efficiency of the collector may be determined using different liquids in the collector box. Study can also be carried out using a series of lenses of different sizes and of collectors of different sizes and design to determine the optimum conditions for economy.

III.

Recommendations for Further Experimental Work

The data procured in this study suggests that with only slight modifications, the dynamic or flow collector is quite satisfactory for carrying out further studies. The operational arrangement of the static collector is apparently a satisfactory one; however, the design of the collector should be improved in the following manner: (1) the copper collector should be fitted with Bake-lite Arm supports, (2) with

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exception of its face the copper collector should be completely insulated from its surroundings with abestos, and (3) the face should be properly fitted with vycor or pyrex glass plate for the purpose of accomplishing the greenhouse effect.

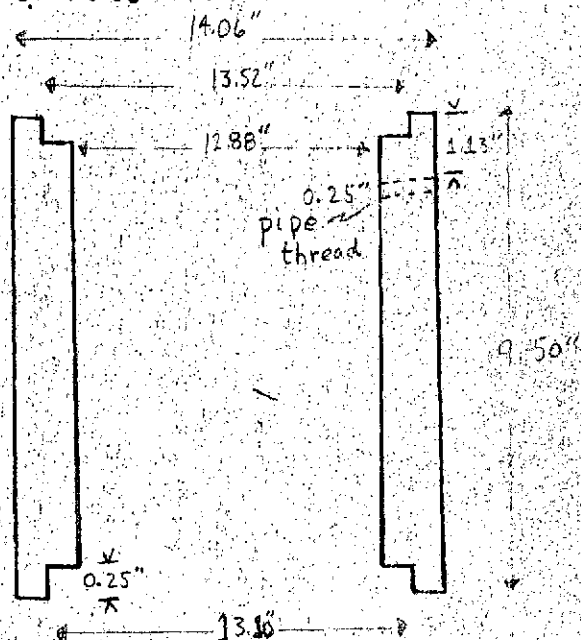
A series of determinations should be carried out on selected liquids, varying from cooking oils to liquid mercury, using the procedure developed in the investigation. Theoretically, temperatures above several hundred degrees should be easily obtained. Subsequent to these studies and after selecting an economical liquids, studies should be carried out by designing a liquid system for absorbing solar energy and transmitting it to a water system flowing over or by the heated liquid.

In the study reported herein, the investigators employed small lens adapted to a small scale system because of economy involved. However, based on the results obtained in this study, in a large scale system one could reasonably anticipate that at least 50% or more of the solar flux could be collected and put to a beneficial use.

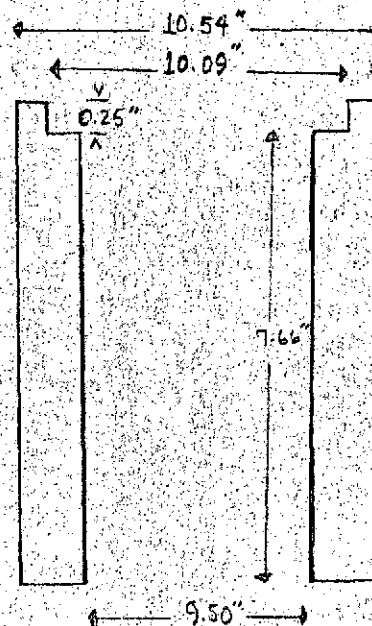
IV. Acknowledgements:

The principal investigator is of the considered judgement that the research reported herein could not have been accomplished without the unpaid help of others. Thus, the principal investigator hereby acknowledged the helpful suggestions and cooperation of Dr. Jack Howell, Professor of Mechanical Engineering, University Office of Research, University of Houston, Houston, Texas, who served as unpaid consultant in connection with this project. Acknowledgement is extended to Mr. Gerry Smith, machinist at the University of Houston, for his help in the construction of the flow collectors. Mr. Leroy Chappell, Refrigeration and Maintenance Engineer, at Texas Southern University, along with his associates, constructed the static heat collector used throughout this research at no cost to the project. Mr. Ulysses S. Short, a Texas Southern University student majoring in mathematics, gave his unselfish help both in procuring the data reported in this study and performing the drafting included herein at no cost to the project. Last, but none the least, Mr. Vernon Shields, the NASA monitor for this research, has given extraordinary service to this project in terms of his time and patience.

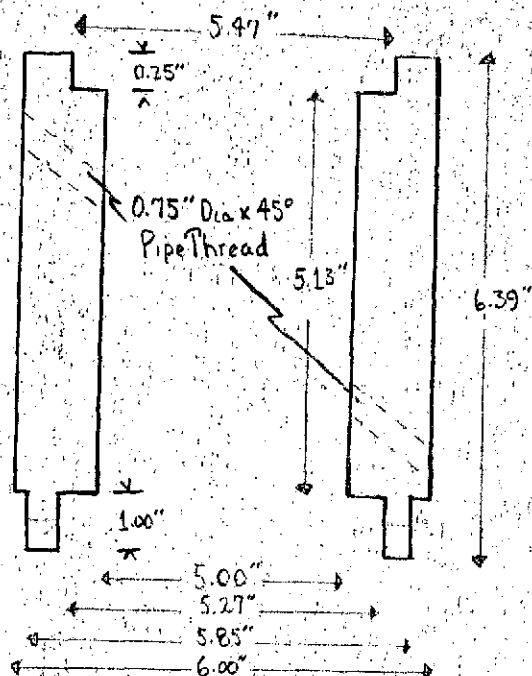
I Outer Tube



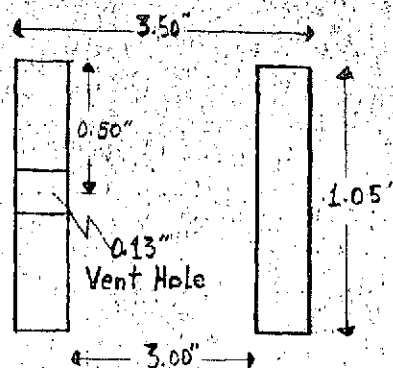
II Middle Tube



III Center Tube

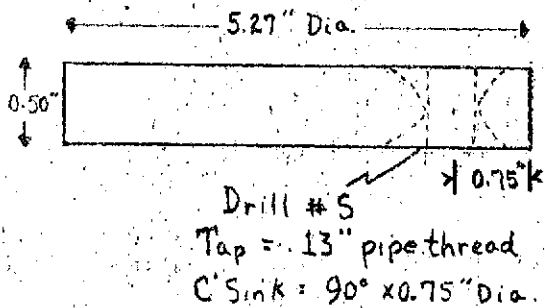


IV Spacer Tube Bottom



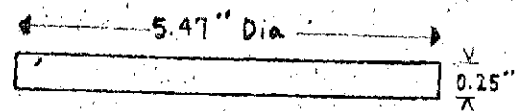
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V Center Tube Top Plug

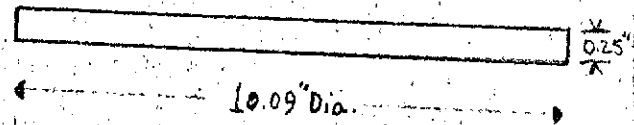


VI Center Tube Bottom Plug

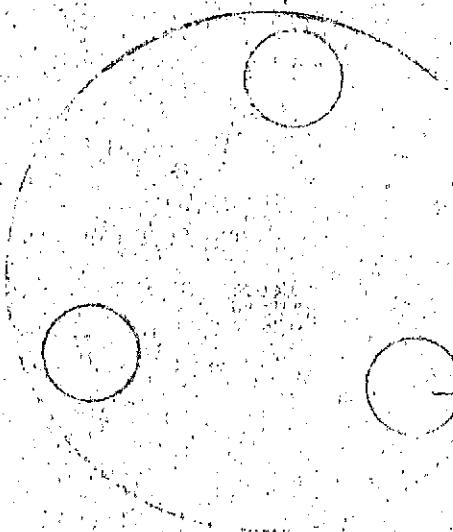
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Middle Tube Bottom



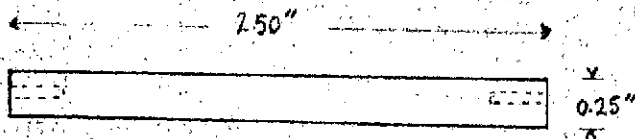
VII Heat Exchanger Plate



Material - Cu
Diameter = 3.00"
Thickness = 0.13"

Three holes are
equally spaced on 2.50" base.

Three Spacer Legs



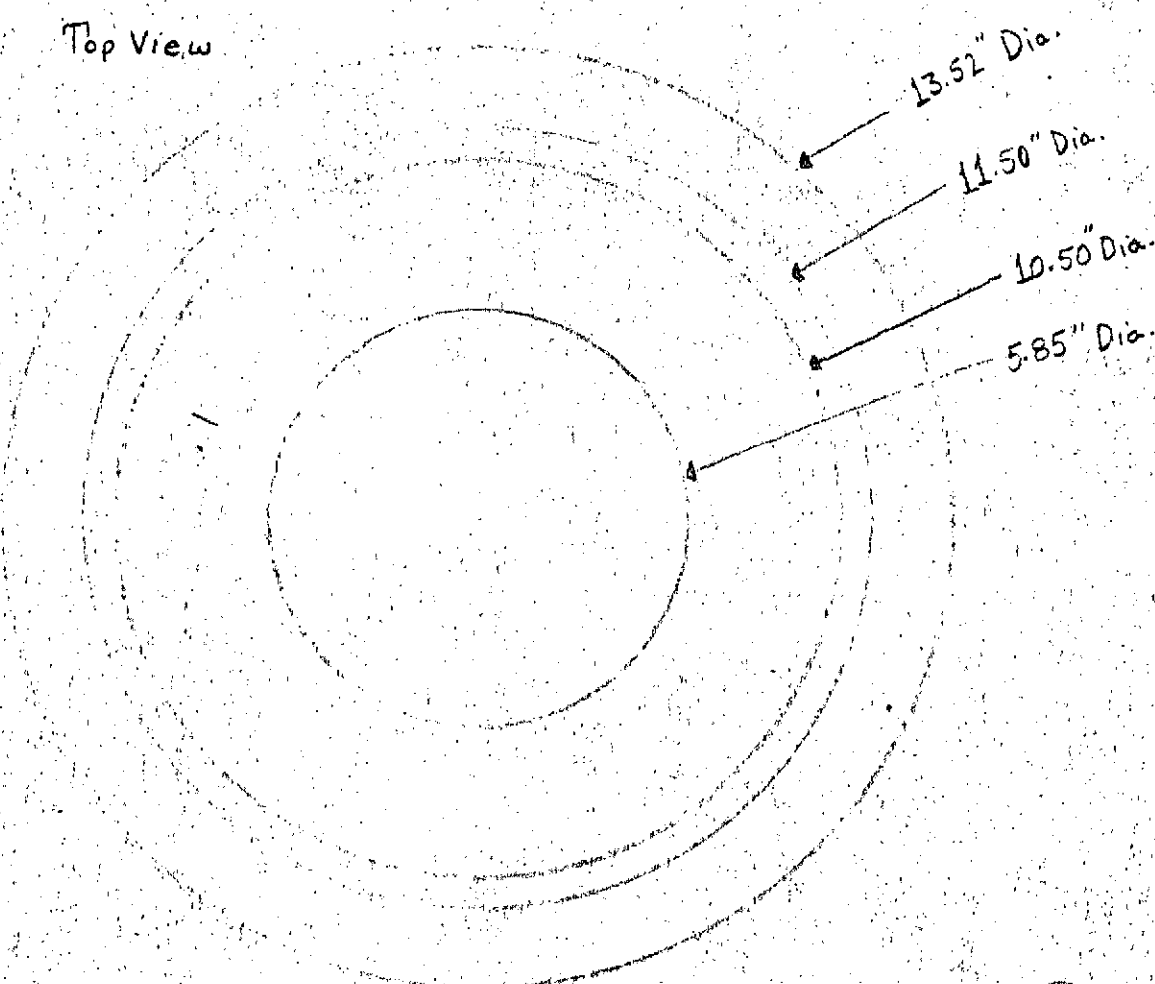
0.30" thread at each end
is 0.75" deep.

Material - Brass

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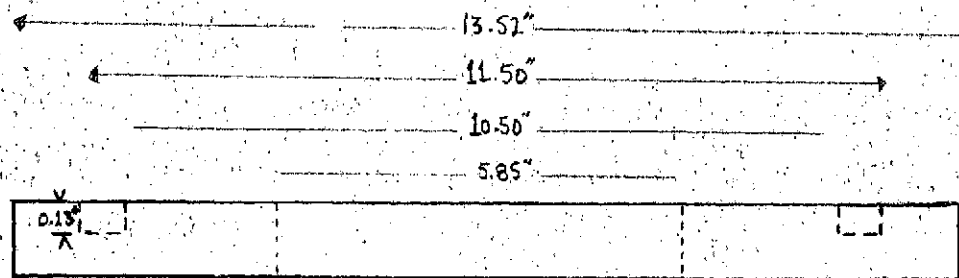
XIII Upper Enclosing Ring

Top View



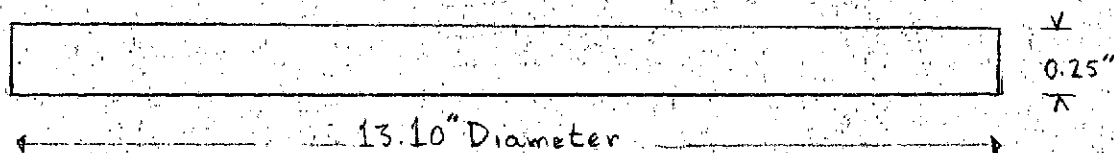
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Front View



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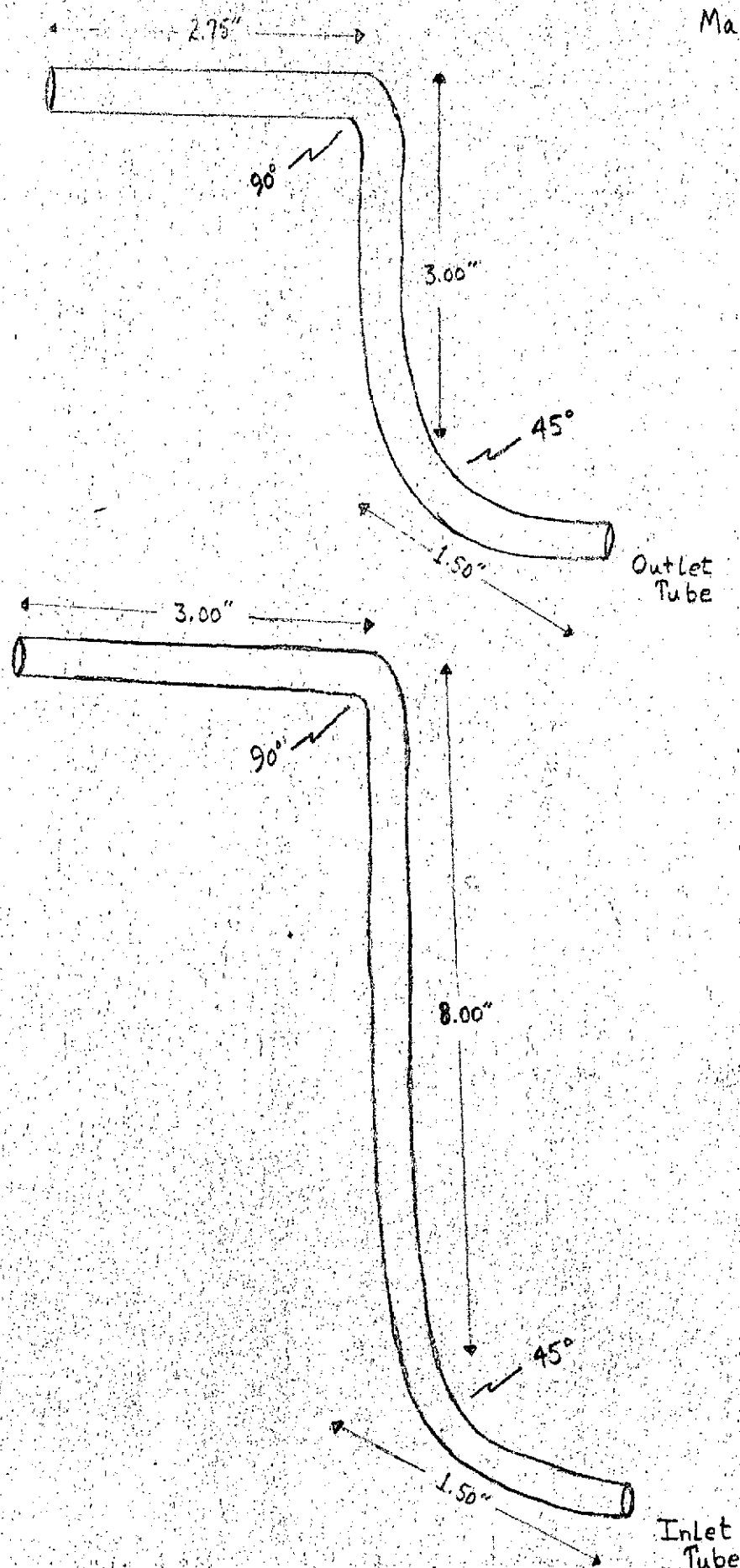
Lower Enclosing Ring



IX Outlet and Inlet Tube

Material - Plexiglas

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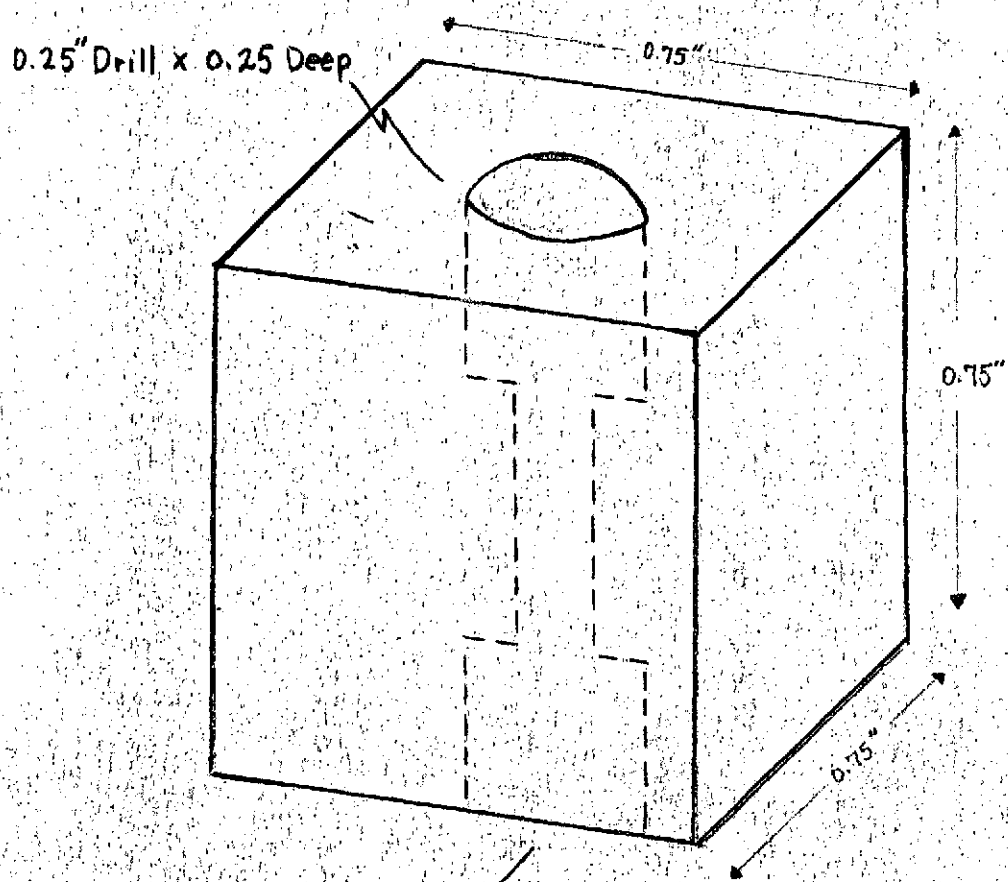
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X INSULATION BLOCKS

Material - Bakelite

Quantity - 3

-1/-



#11 Drill Hole thru
Center Sink 82° x 0.39" deep

Note: Hole centered in block

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TABLE I

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WATER FLOW RATE vs TEMPERATURE DATA

Temperature, °C			Volume of Water Collected, ml	Flow Rate ml/sec	Heat Retained by Collector, Cal.	% Efficiency
T_1	T_2	T_3	V	dV/dt	$\frac{P}{A}$	$100 \frac{P_A}{P}$
27.0	27.0	31.2	250	2.50	10.8	73.5
27.0	27.0	31.5	260	2.60	11.7	79.6
27.0	27.0	31.5	230	2.30	10.3	70.1
27.9	27.9	32.0	240	2.40	9.6	65.3
27.9	27.8	32.0	245	2.45	11.0	74.8
27.9	28.0	32.5	245	2.45	11.0	74.8

(1) Radiometer Readings = 520 Watts/m²

(2) $P(\text{Incident Radiation}) = \frac{(\text{Radiometer Readings}) (\text{Area of Lens})}{4.186}$

$$P = \frac{(520 \text{ Watts/m}^2) (0.118 \text{ m}^2)}{4.186 \text{ joules/cal}} = 14.7 \text{ Cal}$$

(3) $t(\text{flow time}) = 100 \text{ seconds}$

TABLE II

HEATING AND COOLING DATA FOR VEGETABLE OIL

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Time t, min	Heating With Incident Radiation $T, ^\circ\text{C}$	Cooling With Incident Radiation Shut Off $T, ^\circ\text{C}$	$\frac{dT}{dt}$ $^\circ\text{C/min}$	$\frac{dT_r}{dt}$ $^\circ\text{C/min}$	$\left[\frac{dT}{dt} + \left \frac{dT_r}{dt} \right \right]$ $^\circ\text{C/min}$
0	26	122			
1	35	105	3	17	20
2	57	92	5	13	18
3	72	80	9	12	21
4	83	71	13	9	22
5	91	62	13	9	22
6	98	55	11	7	21
7	101	49	15	6	21
8	107	44	17	5	22
9	110	39	17	5	22
10	113	36	15	3	18
11	116	33	15	3	18
12	119	30.5	17	3	20
13		27.0	17	3	20
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- 1) The $\frac{dT_r}{dt}$ values shown in column 5 were determined by taking $\Delta T (^\circ\text{C/min})$ from the cooling data in column 3 where $\Delta T = T_n - T_{(n+1)}$.
- 2) The $\frac{dT}{dt}$ values shown in column 4 were determined analytically using the slope method from a graph of the heating data in column 2 shown in figure 3.
- 3) $\left[\frac{dT}{dt} + \left| \frac{dT_r}{dt} \right| \right] \text{ ave.} = 20^\circ\text{C/min.}$

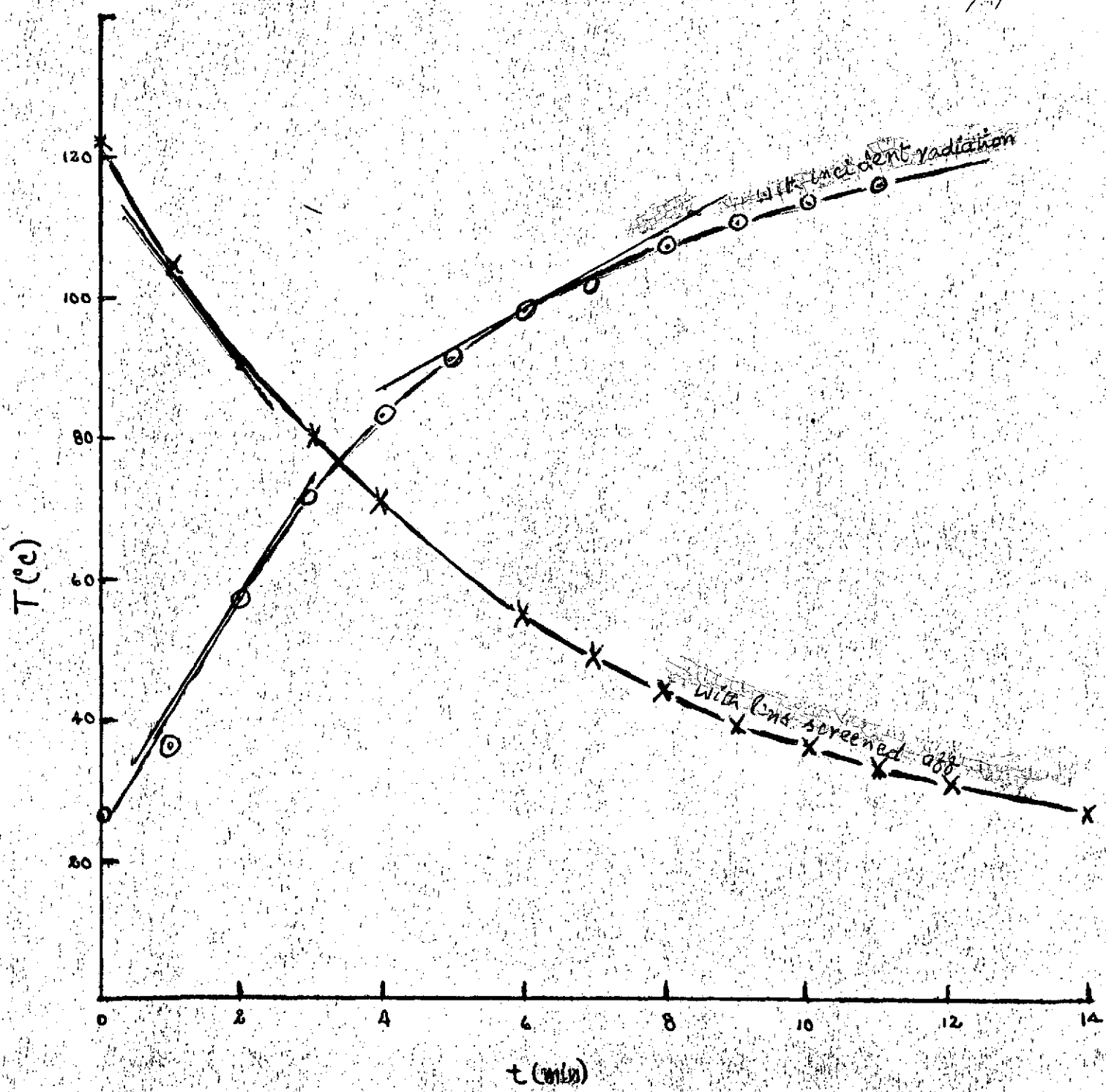


Figure 3